January 8, 1846.

The MARQUIS OF NORTHAMPTON, President, in the Chair.

The following paper was read:—

"Experimental Researches in Electricity." By Michael Faraday, Esq., D.C.L., F.R.S. &c. Twentieth Series. Section 26th. "On New Magnetic Actions; and on the Magnetic Condition of all Matter."

The following is the order in which the several divisions of the subject treated of in this section of the author's researches in electricity succeed one another:—1. Apparatus required. 2. Action of magnets on heavy glass. 3. Action of magnets on other substances acting magnetically on light. 4. Action of magnets on the metals generally. 5. Action of magnets on the magnetic metals and their compounds. 6. Action of magnets on air and gases. 7. General considerations.

In giving an account of the contents of this paper, any attempt to follow the track of the author in the precise order in which he relates the consecutive steps of his progress in this new path of discovery, would fail of accomplishing its object; for, by adhering to such a course, it would scarcely be possible to comprise within the requisite limits of an abstract the substance of a memoir extending, as the present one does, to so great a length, and of which so large a portion is occupied with minute and circumstantial details of experiments; or to succeed in conveying any clear and distinct idea of the extraordinary law of nature brought to light by the author, and of the important conclusions which he has deduced.

One of the simplest forms of experiment in which the operation of this newly-discovered law of magnetic action is manifested, is the following:—A bar of glass, composed of silicated borate of lead, two inches in length, and half an inch in width and in thickness, is suspended at its centre by a long thread, formed of several fibres of silk cocoon, so as to turn freely, by the slightest force, in a horizontal plane, and is secured from the agitation of currents of air by being enclosed in a glass jar. The two poles of a powerful electro-magnet are placed one on each side of the glass bar, so that the centre of the bar shall be in the line connecting the poles, which is the line of magnetic force. If, previous to the establishment of the magnetic action, the position of the bar be such that its axis is inclined at half a right angle to that line, then, on completing the circuit of the battery so as to bring the magnetic power into operation, the bar will turn so as to take a position at right angles to the same line; and, if disturbed, will return to that position. A bar of bismuth, substituted for the glass bar, exhibits the same phenomenon, but in a still more marked manner. It is well known that a bar of iron, placed in the same circumstances, takes a position coincident with the direction of the magnetic forces; and therefore at right angles with the position taken by the bar of bismuth subjected to the same influence. These two directions are termed by the au-

thor *axial* and *equatorial*; the former being that taken by the iron, the latter that taken by the bismuth.

Thus it appears that different bodies are acted upon by the magnetic forces in two different and opposite modes; and they may accordingly be arranged in two classes; the one, of which iron is the type, constituting those usually denominated *magnetics*; the other, of which bismuth may be taken as the type, obeying a contrary law, and therefore coming under the generic appellation of *diamagnetics*. The author has examined a vast variety of substances, both simple and compound, and in a solid, liquid, or gaseous form, with a view to ascertain their respective places and relative order with reference to this classification. The number of simple bodies which belong to the class of magnetics is extremely limited, consisting only of iron, which possesses the magnetic property in an eminent degree, nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum and osmium. All other bodies, when either solid or liquid, are diamagnetic; that is, obey the same law, with regard to magnetic action, as bismuth, but with various degrees of intensity: arsenic is one of those that give the feeblest indications of possessing this property. The following exhibit it in increasing degrees, according to the order in which they are here enumerated; namely, ether, alcohol, gold, water, mercury, flint glass, tin, lead, zinc, antimony, phosphorus, bismuth. On the other hand, no gaseous body of any kind, or in any state of rarefaction or condensation, affords the slightest trace of being affected by magnetic forces. Gases may therefore be considered as occupying the neutral point in the magnetic scale, intermediate between magnetic and diamagnetic bodies.

The magnetic properties of compound bodies depend on those of their elements; and the bodies are rendered either magnetic or diamagnetic according to the predominance of one or other of these conditions among their constituent parts. Thus iron is found to retain its magnetic power when it has entered into combination with other bodies of the diamagnetic class; the two forces acting in opposition to one another, and the resulting effect being only that due to the difference in their power. Hence the oxides and the salts of iron are still in a certain degree magnetic, and the latter even when they are held in solution by water; but the water may be present in such a proportion as that neither shall prevail; and the solution, as far as respects its magnetic properties, will then be exactly neutralized. These saline solutions, prepared of various degrees of strength, also afford a convenient method of comparing the relative degrees of force, both magnetic and diamagnetic, of different bodies, whether solid or fluid, but more especially the latter, as they admit of the body under examination being suspended in another liquid, when its position of equilibrium will indicate which of the two substances has the strongest magnetic power.

In one respect, indeed, the diamagnetic action presents a remarkable contrast with the magnetic; and the difference is not merely one of degree, but of kind. The magnetism of iron and other magnetics is characterized by polarity; that of diamagnetics is devoid of any

trace of polarity; the particles of two bodies of the latter class, when jointly under the influence of the magnetic forces, manifest towards each other no action whatever, either of attraction or repulsion. It has long been known that the magnetism of iron is impaired by heat; and it has been generally believed that a certain degree of heat destroys it entirely. The author finds, however, that this opinion is not correct; for he shows that, by applying more powerful tests than those which had been formerly confided in, iron, nickel and cobalt, however high their temperature may be raised, still retain a certain amount of magnetic power, of the same character as that which they ordinarily possess. From the different temperatures at which the magnetic metals appear to lose their peculiar power, it had formerly been surmised by the author that all the metals would probably be found to possess the same character of magnetism, if their temperature could be lowered sufficiently; but the results of the present investigation have convinced him that this is not the case, for bismuth, tin, &c. are in a condition very different from that of heated iron, nickel or cobalt.

The magnetic phenomena presented by copper and a few other metals are of a peculiar character, differing exceedingly from those exhibited by either iron or bismuth, in consequence of their being complicated with other agencies, arising from the gradual acquisition and loss of magnetic power by the iron core of the electro-magnet, the great conducting power of copper for electric currents, and its susceptibility of being acted upon by induced currents of magneto-electricity, as described by the author in the first and second series of these researches. The resulting phenomena are to all appearance exceedingly singular and anomalous, and would seem to be explicable only on the principles referred to by the author.

Pursuing his inductive inquiries with a view to discover the primary law of magnetic action from which the general phenomena result, the author noticed the modifications produced by different forms given to the bodies subjected to experiment. In order that these bodies may set either axially or equatorially, it is necessary that their section, with reference to the plane of revolution, be of an elongated shape: when in the form of a cube or sphere they have no disposition to turn in any direction: but the whole mass, if magnetic, is attracted towards either magnetic pole; if diamagnetic, is repelled from them. Substances divided into minute fragments, or reduced to a fine powder, obey the same law as the aggregate masses, moving in lines, which may be termed *diamagnetic curves*, in contradistinction to the ordinary magnetic curves, which they everywhere intersect at right angles. These movements may be beautifully seen by sprinkling bismuth in very fine powder on paper, and tapping on the paper while subjected to the action of a magnet.

The whole of these facts, when carefully considered, are resolvable, by induction, into the general and simple law, that while every particle of a magnetic body is attracted, every particle of a diamagnetic body is repelled, by either pole of a magnet. These forces continue to be exerted as long as the magnetic power is sustained,

and immediately cease on the cessation of that power. Thus do these two modes of action stand in the same general antithetical relation to one another as the positive and negative conditions of electricity, the northern and southern polarities of ordinary magnetism, or the lines of electric and of magnetic force in magneto-electricity. Of these phenomena, the diamagnetic are the most important, from their extending largely, and in a new direction, that character of duality which the magnetic force was already known, in a certain degree, to possess. All matter, indeed, appears to be subject to the magnetic force as universally as it is to the gravitating, the electric, the cohesive and the chemical forces. Small as the magnetic force appears to be in the limited field of our experiments, yet when estimated by its dynamic effects on masses of matter, it is found to be vastly more energetic than even the mighty power of gravitation, which binds together the whole universe: and there can be no doubt that it acts a most important part in nature, and conduces to some great purpose of utility to the system of the earth and of its inhabitants.

Towards the conclusion of the paper, the author enters on theoretical considerations suggested to him by the facts thus brought to light. An explanation of all the motions and other dynamic phenomena consequent on the action of magnets on diamagnetic bodies might, he thinks, be offered on the supposition that magnetic induction causes in them a state the reverse of that which it produces in magnetic matter: that is, if a particle of each kind of matter were placed in the magnetic field, both would become magnetic, and each would have its axis parallel to the resultant of magnetic force passing through it; but the particle of magnetic matter would have its north and south poles opposite to, or facing the contrary poles of the inducing magnet; whereas, with the diamagnetic particles, the reverse would obtain; and hence there would result, in the one substance, approximation; in the other, recession. On Ampère's theory, this view would be equivalent to the supposition that, as currents are induced in iron and magnetics, parallel to those existing in the inducing magnet or battery wire, so, in bismuth and other diamagnetics, the currents induced are in the contrary direction. As far as experiment yet bears upon such a notion, the inductive effects on masses of magnetic and diamagnetic metals are the same.

January 15, 1846.

The MARQUIS OF NORTHAMPTON, President, in the Chair.

James B. Neilson, Esq. was elected a Fellow of the Society.

"On the Viscous Theory of Glacier Motion." By James D. Forbes, Esq., F.R.S. &c. Part II. "An attempt to establish by observation the Plasticity of Glacier Ice."